**SPECTRAL MIXING MODELS OF S-TYPE ASTEROIDS:** Beth E. Clark, Paul G. Lucey, Jeffrey F. Bell, and Fraser F. Fanale, Planetary Geosciences, University of Hawaii at Manoa, Honolulu, Hawaii, 96822

**Introduction:** This paper presents the results of an attempt to determine S-Type asteroid mineralogies with the use of Hapke theory spectral mixing modelling [1]. Previous attempts to understand the spectral variations present in this single class of asteroids have concentrated on spectral parameters such as absorption band center wavelengths, band area ratios, and geometric albedos [2, 3]. The procedure taken here is to utilize the Hapke spectral reflectance model to calculate single scatter albedo as a function of wavelength for a suite of candidate end-member materials. These materials are then mixed linearly in single scatter albedo space and the mixture is converted, assuming intimate particle mixing, back to reflectance for the spectrum matching routine. A total of 39 S-Type asteroids selected from the Bell et al. survey [4], have been matched with mixture model spectra.

**Procedure:** It is customary when analyzing asteroid spectral data to first normalize the spectra to 1.0 at 0.56 microns, thus eliminating albedo information until other means of analysis are completed. Part of the rationale behind this has been the fact that asteroid albedos are not known to a high degree of confidence, and cannot therefore be used as anything but rough guides as to asteroidal composition. For this paper, we first quantify the uncertainty in model composition which may be due to poorly constrained albedo. Next, we take the available published IRAS albedos to be the actual reflectance at 0.56 microns for each asteroid. The end-members we used are low-iron orthopyroxene and clinopyroxene, nickel-iron metal from the DRP IIAB meteorite, forsteritic olivine, and anorthositic plagioclase. All spectra of end-members were measured at the RELAB facility at Brown University [5, 6, 7]. In addition to the meteoritic metal component, a dark, spectrally flat absorber was added to the set of end-members after initial attempts to use only metal resulted in systematic over-redening of mixture model spectra. Scattering properties of the mafic minerals were approximated by taking an average of the Legendre polynomial coefficients of mafic minerals analyzed by [8]. Each end-member has three different grain size ranges: < 45 microns, 45 - 75 microns, and 75 - 125 microns. To minimize procedural differences, spectra were first interactively fit with mixtures at the 45 - 75 micron average grain size range. In only two of thirty-nine S-Type spectra was a match with this grain size range impossible to achieve, whereas both other ranges resulted in strange average model compositions. Thus we make the preliminary assumption that S-Type asteroids have surface optical properties dominated by a 45 - 75 micron grain size fraction. Although this is probably an oversimplification of the actual surface grain size distribution we take it as a starting point until more information becomes available.

**Results:** Shown in Figure 1 are the compositions resulting from the model fits in terms of clinopyroxene vs. orthopyroxene, both values being normalized to total percentage mafic silicates. The lack of structure or clumping in this figure suggests that if important subgroups exist within the S-type population, their cpx to opx ratios form a smooth continuum and thus some other criteria is necessary for subgroup identification. In general, the spectral subgroups within the S-type asteroid population which have been identified by Gaffey et al. [3], have been verified by this analysis. These subgroupings were identified based on their positions on a plot of band I area/band II area versus band I center position, a technique which appears to concentrate on the relative strength of the mafic absorption bands. We note, however, that a spectrum which appears to reflect an olivine/metal-rich assemblage may also be modelled with a mixture of plagioclase and clinopyroxene with equally minimized residuals. This possibility is indeed mildly suggested by the correlation seen in Figure 2. Thus, unless independent evidence is brought to bear, the non-uniqueness of these model fits is a considerable constraint on their usefulness. It is possible that ambiguities may be resolved by higher-precision fitting with different end-member minerals. This possibility will be explored in future.

**Discussion:** The largest single source of potential error in mixing model analyses is in the choice of end-member minerals. This is because the single-scatter albedo has been shown to be the most important Hapke parameter in characterizing mineral spectral properties, leaving refinements such as the phase function coefficients, the reflection geometry, and other parameters of secondary importance [8, 9]. Single particle phase function coefficients are however, important for the metallic component. We found that incorrect values of phase coefficients resulted in differences of overall reflectance of model spectra of up to 40%, which is quite significant when the albedo is an important parameter. Because the phase coefficients have not been measured specifically for the nickel-iron metal used here we chose to take the
average of the scattering properties of those types of metal that were measured by [8]. We note, however, that this is a potentially important source of error, and it seems that much work remains to be done before we fully understand the role of metallic components in mineral mixtures. Finally, we note several systematic errors in the results that were, given the end-members and grain sizes discussed above, impossible to eliminate. The first was a very consistent mismatch in the spectral shapes of the actual and model spectra in the wavelength regions of 0.3 to 0.5 microns and from 2.2 to 2.5 microns. The residual errors in these regions could very often be minimized by a balanced exchange of the spectrally flat neutral component with the metallic nickel-iron component. Thus if these errors were not due to choice of silicate mineral end-members, their source may lie in the inappropriate representation of the metallic component of S-type asteroid mineral mixtures.

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Figure 1 Compositions resulting from Hapke model fits to 39 S-Type asteroids from the Bell et al. survey [4]. Note the lack of structure and clumping.

Figure 2 Compositions of the same S-Type asteroid model fits as above, showing a rough correlation between total clinopyroxene and total olivine among the mafic mineral components. This correlation may be due in part to the non-uniqueness of spectral model fits, i.e. a spectrum which can be fit with olivine and metal can be fit equally well with clinopyroxene and plagioclase.